APPENDIX D
DESIGN EXAMPLES

The following example illustrates the approach and the procedures used in designing a full-scale land treatment unit. Since land treatment is intended to be "low" technology, this example strives to utilize non-specialized labor, materials, and equipment whenever possible.

EXAMPLE: Remediation of Diesel-Contaminated Soils

A. Background

A valve leak in a tank farm has resulted in a spill of approximately 3,785 1 (1,000 gal) of No. 2 diesel fuel. The site is in Missouri, with an anticipated 7 month season (April - November). The annual net transpiration rate (precipitation minus evaporation) is assumed to be zero. The site assessment determines the following information:

- The spill covers the entire floor of the containment area. The inside of the containment is 30.5 m x 30.5 m (100 ft x 100 ft).

- The tank inside the containment area is a 10.7 m (35 ft) diameter vertical tank. The tank is constructed upon a deep ring wall. Therefore, the valve leak has not resulted in the contamination of soils below the tank.

- A second containment area has been located in which the storage tank has been demolished and removed. This area has been identified as a potential treatment area for the contaminated soils. The containment area is 30.5 m x 30.5 m (100 ft x 100 ft) with a 1.8 m (6.0 ft) dike. The dike consist of crushed limestone with side slopes of 1H:1V.

- Soil borings indicate soils below the containment area floor consists of a silty fine sand (SP) to a depth of 3.6 m (12 ft), where a fractured siltstone is encountered. Water is encountered 2.1 m (7 ft) below the surface.

- Borings also indicate soils are contaminated to an average depth of 1.2 m (4 ft). Analytical testing of soils within the contaminated zone determines the following average concentrations of target volatiles and semi-volatiles:

naphthalene	9	ppm
chrysene	11	ppm
fluorene	12	ppm
benzo(a)anthracene	8	ppm
benzo(a)pyrene	9	ppm
BETX (total)	12	ppm

The average soil TPH has been measured at 2,000 mg/kg in soil.

B. Regulatory Requirements

- Based on risk assessment data, the following clean-up criteria have been established:

naphthalene	2	ppm
chrysene	2	ppm
fluorene	2	ppm
benzo(a)anthracene	2	ppm
benzo(a)pyrene	2	ppm
BETX	2	ppm

No cleanup standard has been set for TPH.

- The design storm to be used for stormwater management design is the 25-year/24-hour storm. This is a 12 cm (4.7 in) rainfall event for this site.

- Since short-term inundation will have no detrimental impact on the treatment operations, it is not required that the stormwater be removed at the maximum instantaneous rate (e.g., 25-year/30-minute intensity) However, the stormwater should be removed within a 24-hour period.

- Because this contaminated soil is exempted from RCRA, state-established containment standards are applied to this treatment cell. Based on state guidance, the treatment cell will be lined with a 60-mil geomembrane liner. The liner design must provide sufficient controls to prevent damage during soil placement, tilling and removal operations

- Based on state guidance, the leachate and stormwater will be collected, treated and discharged in accordance with the facility's existing NPDES permit.

C. Treatment Approach

Because removing the contaminated soil as quickly as possible will minimize the potential impact on the shallow ground water, all of the contaminated soils will be excavated to the required clean-up level (e.g., to a depth of 1.2 m (4 ft)). The only area identified as a potential treatment area has insufficient space to treat the soils in a single lift, so the following scenario is proposed:

- The treatment cell will be lined to prevent migration of the constituents to the groundwater. The liner will extend up the sides of the cell so that the full capacity of the cell may be utilized.

- A leachate collection system will be installed.

- A liner protection system will be installed to protect against liner damage during soil placement and removal operations and tilling operations.

- All of the contaminated soil will be stockpiled into the lined cell.

- The active treatment zone will consist of the uppermost 30 cm (12 in) of the soils stockpiled in the treatment cell. That uppermost zone will be treated until the target constituent concentrations have been reduced to levels below the regulatory clean-up criteria.

- Upon meeting the regulatory clean-up criteria, the upper 30 cm (12 in) treatment zone will be removed and used as fill or stockpiled elsewhere on site.

- The subsequent 30 cm (12 in) of contaminated soil within the treatment cell will be treated until the constituent concentrations are below the regulatory clean-up criteria and subsequently removed. This procedure will continue until all of the soils within the treatment cell have been treated and removed.

- The facility does not have on-site wastewater treatment facilities. Therefore, the design will incorporate additional water storage capacity, so that stormwater and leachate may be used to irrigate the site.

- When the soil treatment is completed, a decision will be made to either decontaminate and decommission the treatment cell liner and equipment, or reuse this cell to treat additional soils similarly contaminated.

One particular advantage to this approach is that some degradation of constituents can be expected to occur at depths below the 30 cm (12 in) active treatment zone, as a result of oxygen diffusion into the soils. This should help to reduce the time required for treatment of subsequent lifts. However, this benefit is not typically accounted for in the design of the treatment cell.

D. Treatability Testing

Treatability testing determined the following half-lives, in days, of the constituents:

naphthalene	8
chrysene	58
fluorene	80
benzo(a)anthracene	76
benzo(a)pyrene	89
BETX	6

Evaluating current concentrations and target clean-up concentrations indicates that all of the constituents will take about 2.5 to 3.0 half lives to achieve their cleanup goals from their present concentrations. However the length of the half lives for fluorene and benzo(a)pyrene are significantly longer than other target constituents and should control the duration of each lift's treatment. Based on its starting concentration and half-life from the treatability, fluorene will require the longest treatment period estimated to be approximately 207 days to treat from 12 ppm to 2 ppm. Conservatively, it is estimated that a minimum of 225 days of treatment should be allowed for each lift of soils.

While all soil trays indicated reasonable degradation rates, optimum conditions for treatment are based on the tray study showing the most rapid treatment of the constituents of concern. That tray used an initial loading of nutrient-nitrogen as granular fertilizer of 60 mg/Kg of soil and nutrient-phosphorus as triple super phosphate of 30 mg/Kg of soil. During the studies, N and available P fell below 5 ppm only at 10 weeks and were resupplemented to 30 and 15 ppm respectively at 10 weeks. The moisture content in the optimum tray was maintained at 50-60% of field capacity for that soil. The pH in that tray's soil was initially 6.9 SU and was maintained between 7.0±0.5 SU. No significant change in pH occurred during the treatability study.

E. <u>Full Scale Design</u>

1. The volume of contaminated soil to be treated is:

$$\left[(30.5m \times 30.5m) - \frac{(10.7m)^2 \pi}{4}\right] \times 1.2m = 1008m^3 \qquad (1319yd^3)$$

2. The depth required within the proposed treatment area to store the contaminated soil can be calculated using the formula for computing the volume for the frustum of a rectangular pyramid (see Figure D-l):

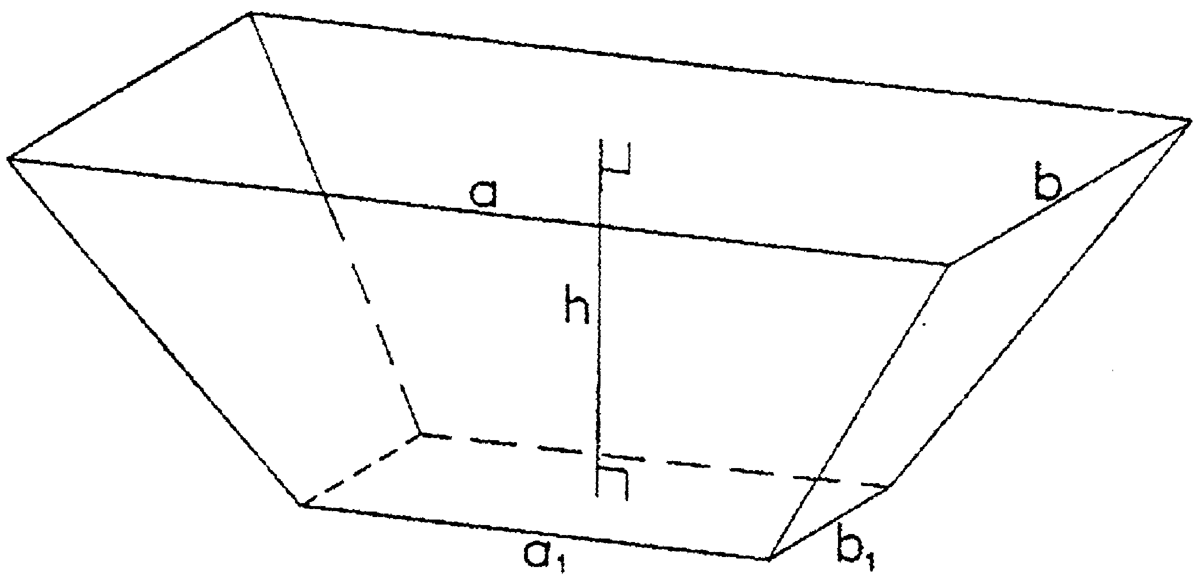

FIGURE D-1
FRUSTUM OF A RECTANGLULAR PYRAMID

$$V = \frac{h\ [(2a+a_1)\ b + (2a_1+a)\ b_1]}{6}$$

a_1 and b_1 represent the dimensions of the inside toe of the treatment area (30.5 m). Since the inside slope of the dike is known and the area is square, a, b_1 and b can be calculated in terms of a_1 and h. Hence, by inserting the "bulked" volume (1008 m^3 x 1.25) and the inside toe dimension (30.5 m), h is determined to be 1.25 m (4.1 ft) by solving the equation iteratively. A plan of the treatment cell is shown on Figure D-2.

3. Since the liner and leachate collection system will require 15 to 20 cm (6 to 8 in), the remaining freeboard may be calculated as:

$$1.8m - 1.25m - 0.20m = 0.35m \quad (1.1ft)$$

This is sufficient to prevent spillage during tilling operations and to provide run-off control. A typical requirement is 1 foot of freeboard.

4. The stormwater storage volume requirements can be computed by multiplying the treatment area by the Rational Method run-off coefficients. For tilled, sandy soils, run-off coefficients are typically 0.1 to 0.15. However, to account for moisture conditions in the treatment cell which are maintained higher than typical crop lands and to account for potential antecedent moisture conditions, a run-off coefficient of 0.35 will be used to provide a conservative estimate. The drainage area consists of the area within the center of the crest of the dike to the center of the opposite dike (i.e., 35 m x 35 m). The total run-off volume can be calculated as:

$$\frac{(35m \times 35m) \times 0.12m}{0.001\frac{m^3}{L}} \times 0.35 = 51.540\ L \qquad (13{,}590gal)$$

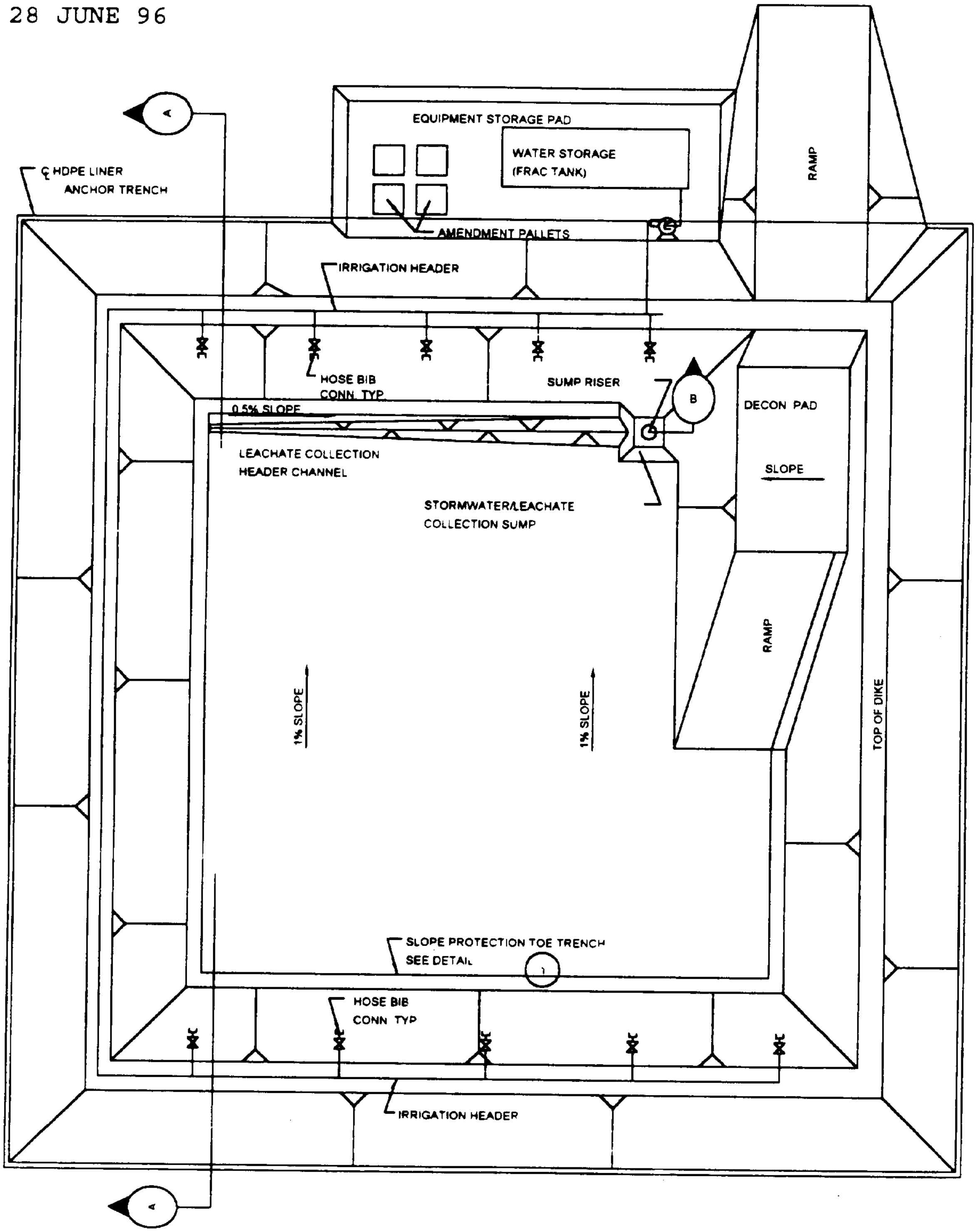

FIGURE D-2
TREATMENT CELL PLAN

If a 75,700 L (20,000 gal) oil field fractionation (frac) tank is used for storage, this tank will have approximately 32% excess capacity. Since it is desirable to maintain at least one-third excess capacity for the purpose of storing water for irrigation, a single frac tank will suffice for water storage. A flow diagram for this treatment unit is illustrated on Figure D 3.

5. Provisions must be made to discharge collected water, in excess of that which can be stored, to the local POTW sewer system. An arrangement is negotiated with the local POTW with the following provisions:

- ! The excess water will be tested for established constituent and BOD_5 concentrations prior to discharge.
- ! Discharge limitations to the POTW sewer are established. Water with constituent concentrations higher than the established limitations must be treated (through activated carbon) and retested prior to discharge.
- ! The quantity of water discharged to the POTW sewer must be measured.
- ! Payment will be based on the quantity of water and BOD_5 concentrations.

6. The collection conveyances, sumps and pumps will be sized to remove the water collected from the 25-year/24-hour storm within 24-hours. The minimum pump capacity is:

$$\frac{51,450\ L}{24\ hours \times 3600 \frac{sec}{hours}} = 0.60 \frac{L}{sec} \qquad (9.4 \frac{gal}{min})$$

Therefore, a pump sized at approximately 0.63 1/s (10.0 gall mm) will suffice.

For temporary systems, pump controls should be kept simple. Typically, an electric sump pump with a float switch will suffice

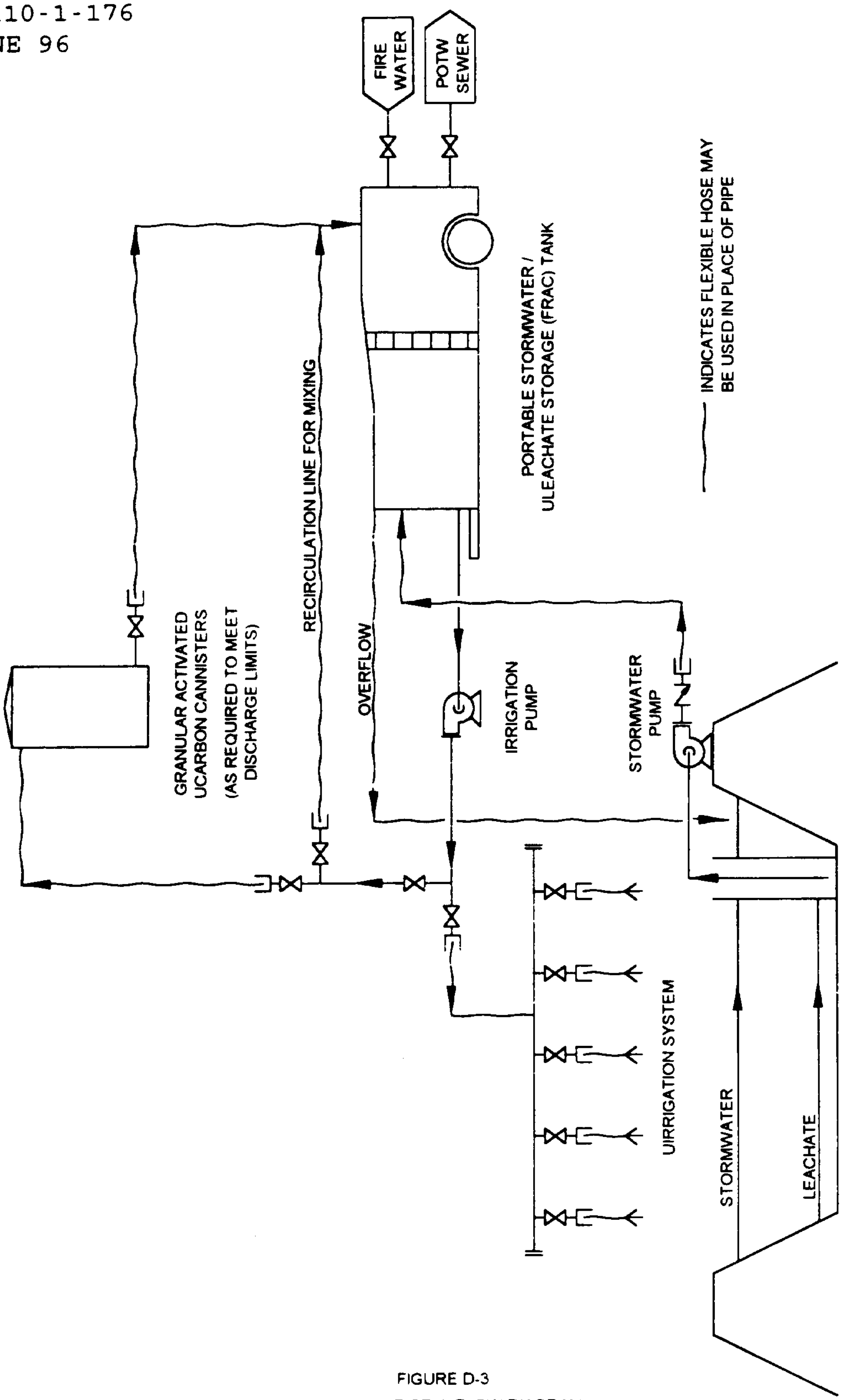

FIGURE D-3
TREATMENT CELL FLOW DIAGRAM

for this project. Where full-time operations personnel are available on-site, a manually operated "trash" pump would be adequate. Overflow protection may be provided by installing a hose from the overflow port of the storage tank back to the lined treatment cell or collection sump.

7. To prevent sediment accretion in the lines, discharge piping from the pump to the storage tank should be sized such that the flow velocities are maintained between 1.2 and 3 m/s (4 and 10 ft/s). On this basis, 2.5 cm (1 in) piping (or hoses) should be used between the pump and the storage tank.

Since the lines from the cell to the stormwater sump are gravity lines, 7.5 to 10 cm (3 to 4 in) diameter pipes should be considered as the smallest line sizes to use for leachate or stormwater collection systems. This will minimize the effect of any sediment accretion in the line and facilitate any line cleaning which may be needed.

8. The liner requirements have been established by state guidance to be 60 mil HDPE liners, so it is not necessary to perform groundwater modeling, contaminant fate-and-transport, and risk assessments in order to establish the groundwater protection criteria. However, the liner should be designed to be protected from soil placement, removal and tilling operations. On the bottom of the cell, this protection is typically provided by placing 15 to 20 cm (6 to 8 in) of gravel or sandy gravel above the liner. The tractor operator will be able to both hear and feel when the disc blades come into contact with the gravel. This gravel is also used as the leachate transmission system to the collection sump. An example section of the treatment cell is shown in Figure D-4.

The coarsest gravel which will prevent the intrusion of the silty fine sand into the leachate collection layer is desired. In landfill applications, poorly graded gravels are often used for the leachate collection layer. Segregation of the leachate collection layer from the finer materials is provided by a geotextile filtration fabric. Since these fabrics are not practical in land treatment applications, a greater emphasis must be placed on the filtration capabilities of the leachate

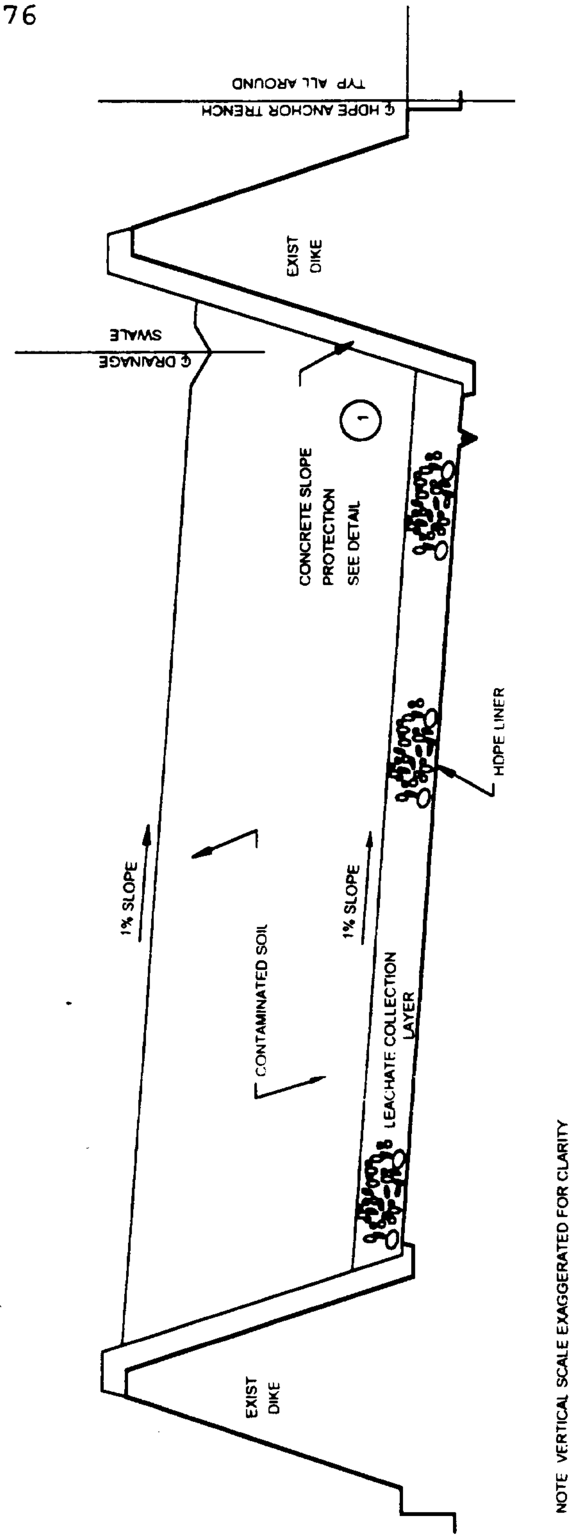

FIGURE D-4
TREATMENT CELL SECTION
A

collection layer. The maximum grain size distribution for the leachate collection layer is determined using Article 50.002-000-000; "Selection of Filter Grain Size and Screen Aperture Size-Selection Criteria," of the *Manual of Water Well Construction Practices,* (USEPA, 1975).

The filter grain size is determined using the 70% retained grain size of the formation. The 70% retained grain size for the contaminated soils is 0.094 mm. Multiplying this value by 5 (the appropriate sediment distribution factor as identified by the above-referenced article) yields 0.47 mm. This is the 70% retained grain size of the filter material to be used.

The referenced article recommends that uniformity coefficients be limited to a maximum value of 2.5 for water wells. This would provide for a sand filter pack with grain sizes ranging from 0.5 mm top 2.0 mm suitable for well development. This limitation is not practical in land treatment applications. This type of sand would not provide sufficient resistance to indicate to the operator when the leachate collection layer is intersected. As a result, an engineered fill is required. For this project, the leachate collection soil should have the following properties:

- Approximately 60% to 70% should be 10 to 20 mm (3/8 to 3/4 in) gravel;

- Approximately 30% should be a No. 40 sand; and

- Less than 5% should pass the No. 200 sieve.

For this project, an AASHTO No. 6 processed aggregate (70% by weight) will be plant-mixed with a washed, No. 40 sand (30% by weight) to produce an engineered fill with the desired properties. Constant head permeability tests on the engineered fill indicate that the permeability was approximately 0.01 cm/s; this is sufficient to conduct the anticipated leachate quantity to the collection header.

9. Since the inside slope of the dike is to be lined with an HDPE liner, it is too steep to effectively retain the gravel

soils. Therefore, a thin layer of concrete will be applied over the lined slope to prevent damage during tilling operations. For this project, a 10 cm (4 in) thick layer of pneumatically placed concrete (Gunite or Shotcrete) reinforced with a welded-wire fabric will be placed on the slopes. Since the concrete is not used for structural or containment purposes, the steel reinforcement is only designed for temperature reinforcement of slabs at grade. The concrete will be keyed into the toe of the slope to provide resistance against sliding. A typical section of this slope protection is shown in Figure D-5.

10. Based upon state guidance for this class of containment system, the minimum slope for the leachate collection system is established at 1.0%. The cell grade slopes in one direction toward a 10 cm (4 in) diameter leachate collection header. The leachate collection header grades toward the stormwater collection sump at 0.5% slope. Based on the estimated leachate production rate, this system has adequate excess flow capacity to account for some sediment accretion within the system.

The collection header should consist of welded HDPE or threaded PVC which has been slotted for the appropriate screen size. Glued PVC should be avoided since the solvents in the glue may be detectable in the leachate analyses. Perforated pipe should be avoided since geotextile wrapping fabrics are to be avoided. In accordance with Article 50.002-000-000; "Selection of Filter Grain Size and Screen Aperture Size-Selection Criteria," of the *Manual of Water Well Construction Practices,* (USEPA, 1975), the maximum opening size should retain 85% to 100% of the filter material. The grain size curve for the engineered fill indicated that the 85% and 100% retained grain sizes are 0.39 mm and 0.18 mm, respectively. The most appropriate slot size is determined to be 0.30 mm, the approximate median between the two reference points. This yields the most transmissive design.

11. The stormwater collection sump is located at the lowest corner within the treatment cell. The sump consists of a slotted 30 cm (12 in) diameter pipe placed vertically. The slotted riser

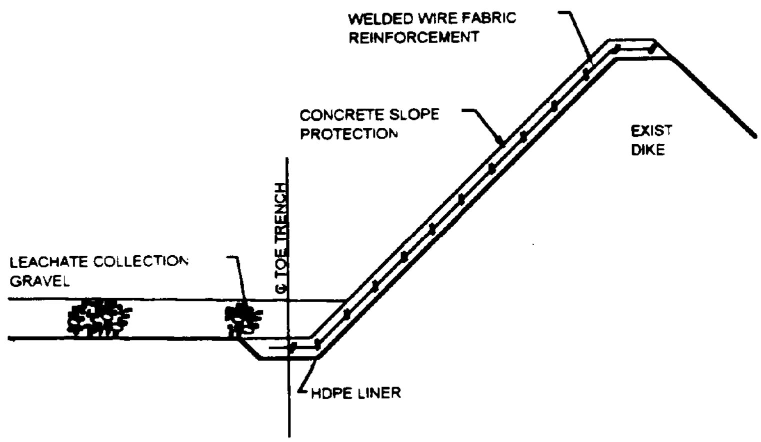

FIGURE D-5
CONCRETE SLOPE PROTECTION DETAIL
1

pipe is installed as shown in Figure D-6. The pipe is placed in a gravel pack in order to increase the flow rate into the sump., In order to keep from "starving" the pump, the gravel pack consists of a clean AASHTO No. 6 graded aggregate (i.e., not mixed with the No. 40 sand). The riser utilizes 5 mm slot openings. The gravel-packed area should be surrounded by a silt fence to minimize sediment accumulation in the sump. A typical section of this sump is shown in Figure D-6.

A sump pump may be placed in the bottom of the riser or a suction hose of a self-priming "trash" pump may be placed in the riser.

12. Entrance and exit ramps are required for the treatment cell. For availability and durability reasons, the ramps are constructed of the AASHTO No. 6 graded aggregate. A thin sand layer is placed upon the bottom liner as a cushion for the interior ramp.

The interior ramp is also used as the decontamination pad. Vehicles exiting the cell are washed on the ramp using water from the frac tank, and the wash water is allowed to drain back into the cell toward the stormwater sump.

13. The contaminated soil need not be placed to a specified density or compaction criteria. The soils in this unit will be end-dumped and spread in one lift by a low ground pressure D-3 bulldozer. Tracking and compaction of the soils is minimized in order to take advantage of any degradation which will occur at depths below the treatment zone.

14. A permanent irrigation system is not required for this cell. Buried systems are typically damaged during earthwork or tilling operations. A fixed monitor system which sprays water across the cell from the dike is typically not required for a temporary treatment cell, and may have difficulty reaching all parts of the cell. This system is designed to consist of a distribution header, garden hoses and lawn sprinklers.

Since neither NCAA pan-evaporation data nor agricultural transpiration data are available for this site, a "rule-of-thumb"

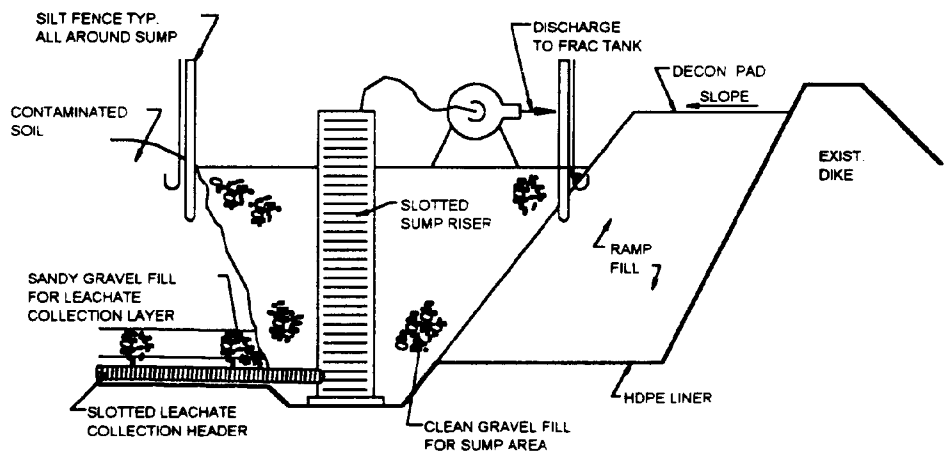

FIGURE D-6
STORMWATER/LEACHATE COLLECTION SUMP SECTION (B)

estimate will be used to size the irrigation system. A "rule-of-thumb" which has been successfully applied to many regions of the continental United States is to design the irrigation system to supply a minimum of the equivalent of 2.5 cm (1 in) of rainfall within an 8-hour period at least once per week. Note that this "rule-of-thumb" is only applied to the sizing of the system. Determination of the actual irrigation requirements is based upon the moisture data collected during operations.

The minimum flow rate of the irrigation system can be calculated as:

$$\frac{[(30.5m \times 30.5m) \times 0.025m] \times 1000\frac{L}{m^3}}{8hours \times 3600\frac{sec}{hour}} = 0.8\frac{L}{sec} \qquad (13\frac{gal}{min})$$

It is not necessary to irrigate the entire cell at once. The irrigation system is designed to deliver the required amount of water to ½ of the cell over a maximum time of 3 to 4 hours. At that point, the irrigation equipment can be moved and the remainder of the site irrigated. To minimize labor requirements, the system should not have to be moved more than once or twice during the day.

Sprinklers are selected from a local lawn and garden shop which deliver 0.5 1/s (8 gal/mm) over a 93 m^2 (1000 ft^2) area at an operating pressure of 310 kPa (45 psi). A design which uses 5 sprinklers was selected because it covers ½ of the area. 1.9 cm (¾ in) garden hoses will be used from the header to the sprinkler to minimize head loss.

A 2.5 1/s (40 gal/mm) pump which matches the required pumping characteristics will be used. Irrigation water should be "dosed" onto the site to ensure the application of the proper amount of water. Therefore, the pump is attached to the discharge valve of the stormwater/ leachate storage tank. Frac tanks typically have a glass level tube used to indicate the water level in the tank. This level indicator can be used to measure how much water has been delivered to the treatment cell. This is a more accurate indication of the quantity of water delivered to the site than a time measurement, since the flow rate may vary as the level in the tank varies.

A firewater service is available near the treatment cell. This firewater service is used to provide make-up water during periods when insufficient stormwater is available for irrigation purposes. Fire hoses are utilized to fill the frac tank to a level adequate for irrigation. The water is pumped to the storage tank so that the quantity of water delivered to the treatment cell can be carefully controlled.

Five irrigation-type tensiometers will be placed in the soil 8 m from each corner and in the center of the cell. These tensiometers will be removed during and replaced after tilling to measure soil moisture (see Section 6.4.1).

15. Based on the results of the treatability study, the primary soil amendments consist of powdered limestone for pH control and a common granular fertilizer for nutrient addition. Since both amendments are dry and spread with a common agricultural spreader, no special storage requirements are required. The amendments are delivered to the site in bags and bound on pallets. Sufficient space is provided on the gravel lay down area next to the frac tank to store several pallets under tarps.

Nutrient concentrations will be measured in the field biweekly using agricultural test kits for ammonium nitrogen and ortho-phosphate. pH will be measured on a 10% slurry of soil in distilled water. The results of these tests will be used to determine when and how much fertilizer and/or limestone to add to the treatment cell.

One additional provision to expedite amendment addition is the recirculation hose from the irrigation pump back to the storage tank. It is occasionally beneficial to be able to add soluble amendments to the irrigation water. The most expedient method is to add the material to the top of the frac tank and circulate the water from the bottom of the tank to the top using the irrigation pump until adequately mixed. This provides an on-site mixer with no additional equipment. To facilitate this, the irrigation system is designed primarily with flexible hoses and "knock-on" connections.

16. The irrigation water is expected to contain small amounts of the contaminants present in the soil. Because the soils are contaminated with diesel fuel, the water will not contain a sufficient amount of BETX or other VOCs to require air emissions control. Some initial monitoring of the top of the frac tank may be necessary.

17. Based on guidance provided by the local SCS County Extension agent, a 30-hp tractor with a 2 m (6 ft) wide rototiller set is used for tilling. The objective is to till the site within a 4- to 6-hour period so the operator will have time to perform at least one other task (e.g. nutrient addition, irrigation, etc.) within an 8-9 hour day.

18. The soils will initially be tilled to a depth of 30 cm (12 inches) biweekly or two days after a rain event of 2.5 cm or more. Tilling frequency will be adjusted after one month of operation, if necessary, based on the soil response to tilling and the progress of remediation.

19. The operating requirements described in Sections 6.3 and 6.4 will be used to guide the remediation progress.